A High-Speed Earthing Switch in Gas-Insulated Metal Enclosed Switchgear

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***Abstract*—A high-speed earthing switch (HSES) is a permanently installed switching apparatus in gas-insulated metal enclosed switchgear (GIS). A spring drive driven HSES has been developed and tested in one-phase and three-phase synthetic test circuit. The HSES rated voltages of 245 kV and 300 kV, enable to performed closing (making) operation on the peak value of short circuit current of 100 kA twice without needing maintenance. This paper presents the main task of an HSES at application in GIS, design characteristics, and two different test procedures. Wide searching throughout standards was made in order to define the real status of this apparatus.**

***Index Terms*—Earthing, gas-insulated metal enclosed switchgear, high-speed earthing switch, high voltage, making current test.**

I. Introduction

THE ACCESSIBILITY to all conductors under potential in gas-insulated metal enclosed switchgear (GIS) technology is prevented by metal envelope and provisional earthing like in the conventional type of air-insulated switchgear (AIS) is not possible. Hence the number of recommended earthing switches is higher in the case of GIS than at AIS. The principles for GIS earthing for maintenance are reflected in three basic concepts [1]:

- Permanently fixed power driven or manual slow operation type devices.
- Permanently fixed power driven or manual (stored energy) fast operation, high-speed type capable of safety making onto a live circuit, of withstanding the associated fault current, and being opened satisfactorily afterwards with no internal damage to the GIS.
- Portable earthing device as an additional tool.

A main option which does not require degassing is the provision of a sufficient number of permanently installed, electrically (as well as mechanically) interlocked, earthing swithces at all possible locations where they may be required within the GIS to allow appropriate maintenance earthing. For this function both types of earthing switch are suitable, i.e., those with capability to close onto a short circuit (short circuit making earthing switches i.e., high-speed earthing switch—HSES) and those without this capability (slow operation types i.e., maintenance earthing switch—MES).

In the use of MES it is a remote possibility that if the appropriate operational permit system and interlocking chain are incorrectly performed then a MES could be closed onto a live busbar and course internal fault with consequential loss of availability of plant and potential operator danger. If the possibilities of such an incorrect earthing switch operation, although small, are unacceptable, then a further option is the application of the HSES at least at line entries or throughout the entire GIS.

Under some local regulations, it is requested that the absence of voltage be verified prior to connecting a conductor to earth. This requirement can be met by an additional voltage probe. If this is not possible with GIS equipment, it may be permitted to replace this operation by closing of the HSES.

Taking into consideration the technical and economical facts, the HSES is mainly used for earthing on incoming line. This HSES must be capable of switching on and off all no load service conditions valid for specific installation, e.g., line-induced capacitive and inductive currents when parallel lines are in service [2].

Portable earthing switch was applied at beginning of GIS technology developmeut as intention to costs reduction of increased number of this apparatus. Their advantage, represented by their minimal installation cost, is more than eliminated by their handling disadvantages. Degassing and removal of the covers are costly in terms of man hours and introduce a danger of internal GIS contamination.

In general, the earthing switch is made with full making capacity; the HSES has been designed with a motor drive and spring. Closing operation consists of the first step while spring being charged to the "dead" point and the second step where the spring is released automatically. The spring releasing led to enough speed of the moving contact to close on the peak value of the short circuit without severe damage. Opening operation has been performed very slow by motor only [3].

Until now the common standard which covers this apparatus in terms of function and tests procedure does not exist. To prove the ability of high-speed earthing switch to carry out a full making test, a few standards have been analyzed and completely or partially applied [4]–[9].

II. HSES Making Test in Basic Standards

During a closing operation onto a short circuit, the high-speed earthing switch contact gap is subjected to the applied voltage corresponding to the r.m.s. value of the rated voltage which causes its breakdown. After this moment, the HSES is subjected to the making current which is expressed by its maximum amplitude i_p in Fig. 1 [7], [8].

In a synthetic test circuit the applied voltage is supplied by a separate voltage source and the short circuit current is supplied by a reduced voltage current circuit. This latter is connected to

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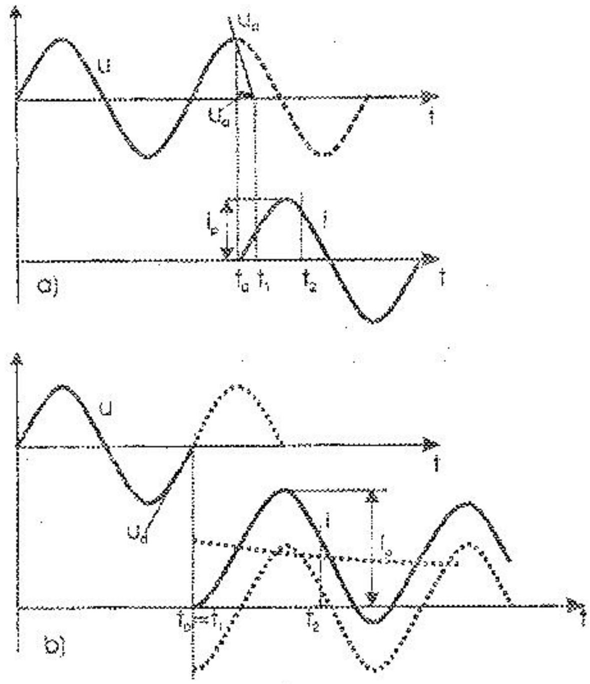

a) Symmetrical making current
b) Asymmetrical making current

i	current
i_p	making current peak
u	power frequency voltage
u_d	dielectric closing characteristic
u_a	arc voltage

Time intervals:

t_0	high voltage interval
$t_0 - t_1$	pre arcing interval
$t_1 - t_2$	latching interval
t_2	fully closed position

Fig. 1. Making test, basic time intervals.

the HSES immediately after breakdown of the contact gap by means of a fast making device, e.g., a triggered spark gap.

Prior to making, an HSES withstands the rated phase to earth voltage applied across its terminals; during making, it carries the rated short circuit current. If closer attention is paid to the voltage and current stresses during the making test, Fig. 1, three main intervals can be registered: high voltage, pre arcing and latching intervals.

A. High-Voltage Interval

The high-voltage interval is the time from the commencement of the test, with the HSES in the open position, to the moment of the breakdown across the contact gap.

During this interval the HSES shall be stressed by the test circuit in such a way that the starting conditions for the pre arcing interval, within the tolerance to be specified, are the same as under reference system condition.

Three-phase tests should preferably be made on three pole switches at the rated voltage of the switch.

TABLE I
TEST VOLTAGE AND CURRENT AT SHORT CIRCUIT MAKING TEST

At test duties	Rated voltage	Test voltage (±10%)	Test current (±10%)	Number of cycles of operation
Three phase tests on three pole switches	All	U	I_p	2 making operation
Single phase test on three pole switches with 0.5 cycles or less non simultaneity	All	U/√3	I_p	2 making operation
Single phase test on three pole switches with more than 0.5 cycles non simultaneity and switches operated pole after pole	All	U 1.5U/√3	$0.87I_p$ I_p	1 making operation 1making operation

Single-phase tests on a three-pole switch may also be made, provided it can be shown that conditions of [9] are met. Additionally, it can be shown that the severity of single-phase tests with regard to the mechanical forces produced on each pole and on the operating device are equal to or more severe than those produced during a three-phase test.

Laboratory limitation at the higher voltage may be such as to make a direct test at rated voltage and rated current extremely difficult. A synthetic making circuit may be used under these circumstances so as to produce the required test voltage from one supply and the rated making current from a second supply.

Under certain conditions, tests may be performed at a reduced voltage. It must be shown that reduced voltage tests are not less severe than tests at the proper voltages, as indicated in Table I [9].

However, when performing synthetic tests on HSES having a high speed and consequently a short pre arcing time, a reduced applied voltage can be used provided that the maximum pre arcing time determined in accordance with [7] does not exceed $1/\omega$ s (3.2 ms for 50 Hz and 2.7 ms for 60 Hz).

A means shall be provided of causing the initiation of arcing on closing at the same distance as that which would be attained at the proper three phase or single phase test voltages. There should be no significant distortion or interruption of the making current during the closing period.

Therefore, the conditions in accordance with sort of test being performed, single-phase or three-phase, and the type of drive shall be met prescription in Table I as well [9].

B. Pre Arcing Interval

The pre arcing interval is the time, during the closing stroke of the HSES, from the moment of breakdown across the contact gap to the touching of the contacts.

During pre arcing the HSES is subjected to electrodynamics forces due to the current and to deteriorating effects due to arc energy. In general, the current is composed of the three components:

- the initial transient making current (ITMC);
- the dc and ac components of the short circuit current.

Two typical cases may occur depending on the moment of closing and on the HSES design.

- Breakdown occurs near the crest of the applied voltage, an almost symmetrical current is established. Pre arc energy and ITMC are relatively high [Fig. 1(a)].
- Breakdown occurs near zero of the applied voltage, an asymmetrical current is established. Pre arcing energy and ITMC are negligible [Fig. 1(b)].
- ITMC is not defined in [8], a value sufficient to maintain pre arcing is adequate.

The short circuit making current shall be expressed as the maximum value of the peak test current for three phase tests, or the peak test current for a single phase test, and shall be at least 100% of the rated short circuit making current in at least one test of the two test required [9]

The tests are considered valid if the peak current in the other test is at least 90% of the rated value or of the specified test current. The symmetrical rms value of current in each pole during the tenth cycle of current shall be at least 80% of the rated short time withstand current.

The duration of the short circuit current shall be at least 10 cycles.

Due to pre arcing, it is not always possible to achieve the required rated shirt circuit making current even though tests are made at the rated voltage of the switch. For this case, evidence shall be given that the making current attained are representative of the currents which will be achieved upon application of the switch at rated voltage in a circuit wherein the maximum prospective peak current is equal to the rated short circuit making current.

C. Latching Interval

The latching interval is the time, during the closing stroke of the HSES, from the touching of the contacts to the moment when the contacts reach the fully closed (latched) position.

During this interval the HSES has to be closed in presence of the electrodynamics force due to the current and contact friction forces.

Therefore, during these intervals, the making current shall comply with [8].

III. Testing and Evaluating

The high-speed earthing switch being installed on the incoming line in the bay has been taken as tested apparatus. The apparatus is one part of a newly developed metal-enclosed SF6 gas-insulated switchgear (GIS) for rated voltages 245 kV and 300 kV. The other rates of this GIS are: short circuit current peak value/rms – 3 s of 100/40 kA and normal continuous current of 4000 A.

By releasing a precharged spring at closing operation, high-speed earthing switch is the fast-acting apparatus with closing time of about 80 ms (from spring realizing moment to the touching of contacts).

During the closing operation and as the contacts approach each other, a point is reached where the gap equals the maximum flashover distance and therefore electric arc is initiated. As the distance between the contacts continues to diminish the arc gradually shortens until finally engage and arc disappears.

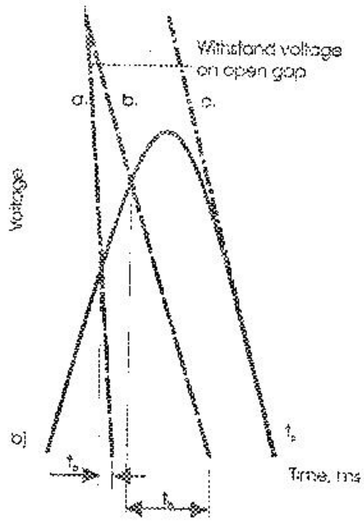

Fig. 2. The HSES setting to the proper speed at the minimum pre arcing time.

Depending upon the voltages, conditions of quenching media and the design of each particular part of the switch, the contact flashover characteristics vary very widely. As it can be seen in Fig. 2, three characteristics slopes were settled and checked. When these slopes are superimposed on the plot of the absolute values of a sinusoidal wave that represent the system voltage, it shows, that depending on the instantaneous relation between the contacts gap and the system voltage the arc is initiated at the point of intersection of the two curves.

The elapsed time between the flashover point and the time where the contacts engage represents the total pre arcing time is shown as t_a, t_b, and t_c corresponding to slopes a, b, and c, respectively. It also can be seen in this figure that the pre arcing time decreases as the slope of the flashover characteristics increases which suggests what should be obvious that increasing the closing speed decreases the arc duration and consequently the contacts erosion. But a higher speed a has reverse impact on the drive energy, the damping system and life time of all parts of mechanism. Some optimum has been found between opposite requirements without additional system for the arc quenching being used.

Apart from the fast action at closing operation this HSES is submitted with arc resistant contacts, Fig. 3.

No additional arc quenching system has been applied. High speed and arc resistance contacts material provide the ability of the HSES to withstand two closing operations on the peak value of the specified short time current, 100 kA and 40 kA rms at latching position.

Opening operation has been performed with low speed and opening time of 1.0 s based on the action of motor drive only.

Two times fully making test on the HSES in synthetic test circuit were performed.

The HSES rated voltage 300 kV, rated making current 100 kA and short time withstand current of 40 kA/3s was tested in one phase synthetic test circuit. This test was based on interpretation of a few standards dealing with the making test procedures of different sorts of switching apparatus in general [6]–[9].

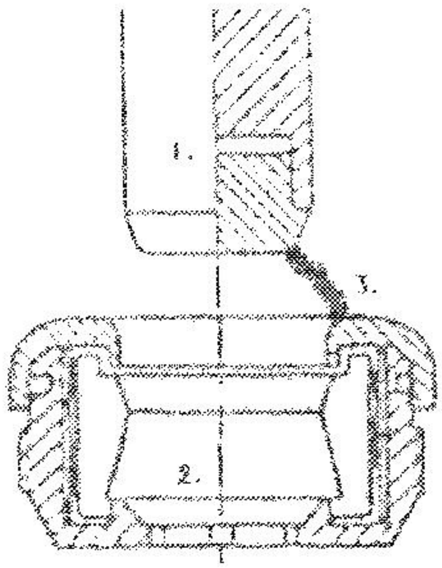

Fig. 3. The HSES contact system. 1) Moving contact, 2) fix contact, 3) pre arc.

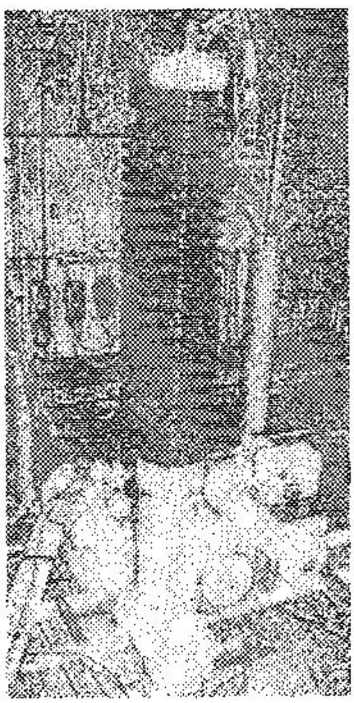

Fig. 4. The HSES 300 kV at making test in one phase synthetic test circuit.

A slightly modified above-mentioned HSES but rated voltage of 245 kV, rated making current of 100 kA and short time withstand current of 40 kA/3s was tested in a three-phase synthetic test circuit. This test was based manly on interpretation of the making test procedures prescribed for circuit breaker [7], [8], [10].

A. The HSES Making Test in One-Phase Synthetic Test Circuit

Test unit consisting of three poles of the one phase enclosed HSES 300 kV mechanically connected together on the common spring drive is shown on Fig. 4.

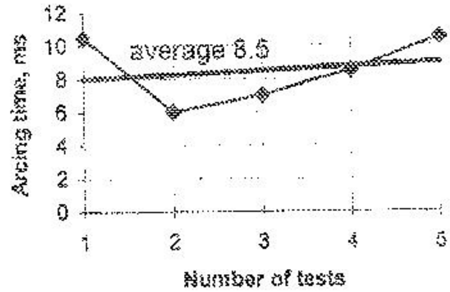

Fig. 5. Pre arcing time values at 170 kV.

A single-phase test on the HSES in synthetic test circuit was performed at lockout, minimum working SF6 gas density and minimum value of the drive supply voltage [11].

In order to obtain in Section II the mentioned requirements combined from many different standards, the next procedure for making test of high-speed earthing switch has been established.

1) The phase of the HSES under test, phase opposite to the driven pole, has been tested by phase to earth rated voltage, 15 min as preconditioning test.
2) In order to measure non simultaneity between poles certain number of no load operation was performed. Because of mechanical connection between poles, very low and less than 0.5 cycles time of non simultaneity has been found. According to Table I, at single-phase test and this value of non simultaneity test can be carried out at phase to earth test voltage, i.e., $300/\sqrt{3} = 173$ kV.
3) In the next step pre arcing times values were measured five times and the test results are given in Fig. 5. As it can be seen, minimum, maximum, and average values of pre arcing time are higher than $1/\omega = 3.18$ ms.
4) To obtain the severity of the single-phase test with regard to the mechanical forces produced on each pole and the operating device equal to those produced during a three phase test and based on the pre test results, a making test has been performed consisting of:
    - one three-phase making operation on $i_p = 107$ kA, r.m.s. values in the three phases of 38.3, 41.1 and 37.8 kA and reduced test voltage of 4.6 kV;
    - two single-phase making in synthetic test circuit of $i_p = 100$ and 98 kA with rms value 39.5 kA at test voltage of 173 kV and pre arcing time about average value; testing time was 0.22 s.
5) Very wide additional tests after the main test were performed.
    - To check insulation conditions after making test, dielectric test by power frequency test voltage of 425 kV, 1 min between phase and earth has been carried out. No discharge was occurred during the test.
    - A certain number of no load operations have been done. The HSES closed and open firmly. No any change in opening and closing time measured before and after test has been recorded.
    - Resistance of the switch in closed position was measured. No any change in results before and after test was found.

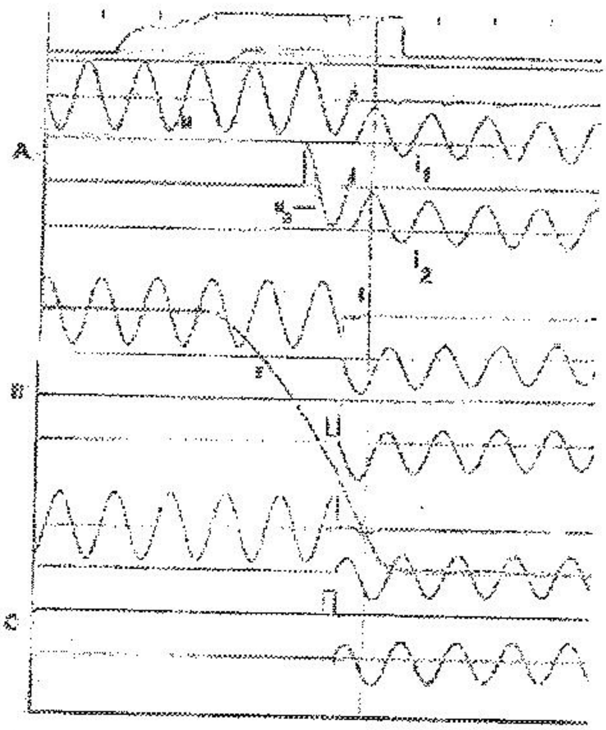

Fig. 6. Measuring values recorded during the making test of the HSES in three phase synthetic test circuit.

B. The HSES Making Test in Three-Phase Synthetic Test Circuit

The HSES rated voltage 245 kV, rated making current 100 kA and short time withstand current of 40 kA/3s was tested in three phase synthetic test circuit [12], [13].

A test object was prepared as in Fig. 4 but with test bushings in all phases installed. Three phase test on the HSES in synthetic test circuit was performed at lockout, minimum working SF6 gas density and minimum value of the drive supply voltage.

The synthetic test method used was a mirror-image of the three phase synthetic break test. Analogous to the three phase synthetic break test for GIS switching apparatus, where two synthetic voltage circuit are used, a synthetic make test was carried out.

Two synthetic voltage sources are used to generate the voltage between the first pre arcing phases (phases 2 and 3), and to generate the voltage to earth for the last pre arcing phase (phase 1). At the moment of the pre arcing the corresponding make gaps are fired, creating a short circuit current path from the generators to the short circuit point. An auxiliary breaker is switched parallel to the make gaps in order to take over the short circuit current, in this way extending the life of the gaps [12].

The network with insulated neutral point and first pole to clear of 1.5 as most severe conditions were simulated in the three phase synthetic test circuit. Hence, at pre test maximum pre arcing time as 9.0 ms at pole with highest voltage of 212 kV was found.

Making test on the HSES was performed two times with pre arcing times on three poles in the range of 7 to 9.7 ms.

In the same time peak value of the making current varied in the range of 69 to 95 kA on different poles.

One of two successfully performed making test recorded values are shown on Fig. 6 [13].

The main parameters were recorded in the three poles, A, B, and C. Phase to earth voltage u, injected "synthetic" voltage u_a, making current in the primary conductor i_1 and return current in enclosure i_2. The stroke of the HSES s was recorded where point t of contacts connection is shown.

Dielectric test, no load operation, and resistance measuring were performed on each pole after test to prove service conditions of complete apparatus. No any irregularities have been found during this tests.

IV. Conclusion

In each point of the GIS switchgear where earthing by mistake on the supply side is very probably, instead ordinary MES, switch with making capability on short circuit current has to be used. This device, with the name high-speed earthing switch (HSES), is not defines until now in any standard regarding application aim and testing procedures.

High-speed earthing switch being installed on the incoming line in the bay, has been taken as tested apparatus. The apparatus is one part of newly developed metal enclosed SF6 gas insulated switchgear (GIS) for rated voltages 245 kV and 300 kV. The other rates of this GIS are: short circuit current peak value/rms.–3 sec of 100/40 kA and normal continuous current 4000 A.

A test unit consisting of three poles of the one-phase enclosed HSES was connected mechanically together on the common spring drive. All tests were performed at lockout, minimum working SF6 gas density and minimum value of the drive supply voltage.

The tested HSES as earthing switch with full making capacity, has been designed with motor drive and spring. Closing operation consists of the first step while spring being charged to the "dead" point and second step where spring is released automatically. The spring releasing led to enough speed of moving contact to close on the peak value of short circuit without severe damage. Opening operation has been performed very slow by motor only.

Apart from high speed and arc resistance contacts, no additional arc diminishing effect was used in this design.

Two times fully making test on the HSES in synthetic test circuit was performed.

The HSES rated voltage 300 kV, rated making current 100 kA and short time withstand current of 40 kA/3s was tested in one phase synthetic test circuit. This test was based on interpretation of a few standards dealing with the making test procedures of different sorts of switching apparatus in general (switches and circuit breakers).

The HSES rated voltage of 245 kV, rated making current of 100 kA and short time withstand current of 40 kA/3s was tested in three phase synthetic test circuit. This test was based manly on interpretation of the making test procedures prescribed for the circuit breaker.

The high-speed earthing switch rated voltage 245 kV and 300 kV without significant modification on crucial parts successfully passed making test in single and three phase synthetic test circuit. To prove service condition of the tested apparatus, additional tests after making test were performed. No any irregularities at these tests were found.

Some significant observation at these tests have been pointed out.

- The electromagnetic repulsion forces are function of the peak current squared and coursed slow down effect on mechanism at the most critical time interval, pre arc shortening. This effect in full scale can not be taken into account in any kind of simulation in single-phase synthetic test circuit.
- Pre arcing time value measured at pre test has predominant effect on the test results. Pre arcing time should be measured at maximum service voltage, i.e., rated voltage but question is at which conditions of the network.
- During the two making tests previous measured pre arcing time should be settled to the same or different value at each test either in single or three phase test circuit. This fact and coordinations between other tests parameters like current and test voltage had the main impact on the behavior of the tested apparatus.
- To be used as safe toll for "operation under failure" or "voltage free proof" [1] can be very dubious task of this apparatus in GIS in service. Till now no evidence about experience on this sort of application has been published. Hence, high-speed earthing switch (HSES) in GIS should found own place in the standards. The clear aim of application and test procedures should be established to avoid sometimes free interpretation of these matters made by manufacturers, users or laboratories.

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